Video Microscopy of Selective Laser Sintering

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Abstract

This paper presents the design and implementation of a video microscopy system that enables real time observation and archival of selective laser sintering of polymer and metal materials. The design objectives and selection of system components are discussed in the first section of this paper. Experimental results from preliminary experiments conducted on polycarbonate, wax and nylon powders are also presented.

Introduction

Current understanding of the dynamics of the Selective Laser Sintering process is based upon theoretical analysis of the process and macroscopic experimentation in real time. In order attain a better understanding the physics of the sintering process, direct experimental observation of the process is an important tool. To facilitate this observation, a video microscopy system has been designed to observe both polymer and metal materials while they are being laser sintered.

The first part of this paper discusses the design objectives and selection of system components for the video microscopy system. The second part presents experimental results from preliminary work done on video microscopy of the selective laser sintering of polycarbonate, wax and nylon powders. Figure 1 shows a schematic of the video microscope camera assembly.

Video microscopy system design

Magnification

The first parameter of the video microscopy system is its magnification. There are two types of magnification used in this system, optical magnification and pixel enlargement.

Optical magnification is produced by the camera lens and is due to the magnification of the light entering the lens. This magnification is referred to here as 'true magnification'. An increase in true magnification results in a larger on screen image, a need for more illumination of the test area, and an decrease in the focal length [Tipler, P. A., p. 885].

Pixel enlargement, or digital magnification, is the result of the electronic transfer of a discrete image from the small viewing area sized one half inch diameter, of the camera to the large presentation area sized 13 inch diagonal, of the monitor. The camera is comprised of a chip with an array of photosensors. The information each sensor receives is a discrete portion of the picture, known as a pixel. The information from the small viewing area is transmitted to the large viewing area electronically. This results in a digital magnification of 20X. A greater digital magnification of 30X is achieved by viewing the process on a 21 inch diagonal monitor.

The problem with pixel enlargement is that it enlarges each pixel in the magnification process, with no regard for the image as a whole. This phenomenon maybe characterized by stating that the more pixel enhancement present, the more grainy and distorted the final image becomes.

In order to reduce graininess and produce a more clear image, the camera and monitor must be carefully chosen. The grainy image is reduced by increasing the number of pixels in the image. Therefore, a black and white camera with 1000 TV lines of resolution and a monitor with 560 TV lines of resolution were chosen for this system. A household TV set has approximately half this number of lines of resolution.

The total magnification requirement for the video microscope system, i.e. the combined optical and digital magnification was set to a minimum of 100X. In order to maintain a reasonable focal length of least four inches, a zoom lens that could focus between 1X and 6X was chosen.

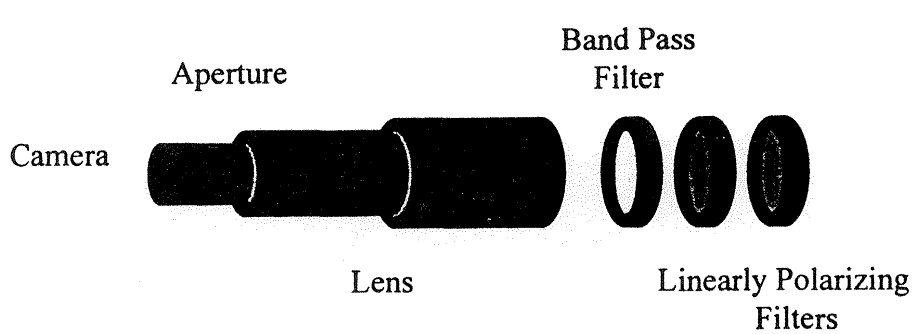

Figure 1
Video microscope camera assembly

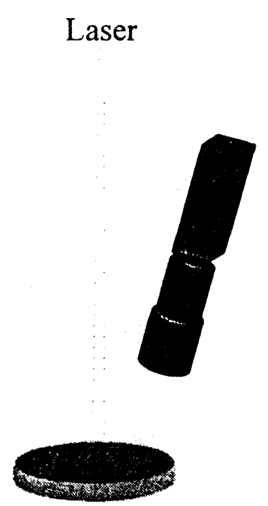

Figure 2
Video microscope viewing position

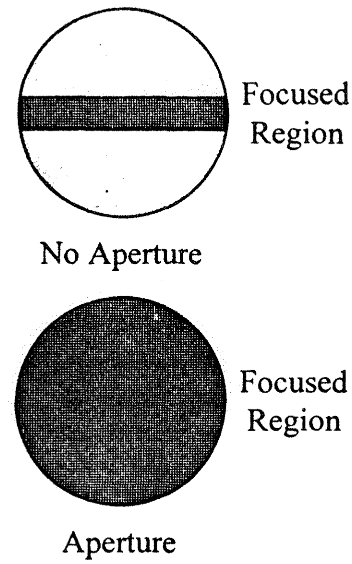

Figure 3
Aperture effect

Aperture

The aperture is one of the most important parts of the video microscopy system. The camera and lens must view the powder bed at an angle to avoid contacting the laser beam as shown in Figure 2 above. The aperture provides depth perception [Reynolds, L.D. and Key, J.F., p. 14], which allows the camera to view the powder bed from an angle. Figure 3 illustrates the difference between an angled system with an aperture, and one without. The system without the aperture can only focus on a narrow band in the field of view, while the system with an aperture can focus on the entire region. The aperture also enables the camera to remain focused on particles which are changing shape in the direction of the camera axis.

The aperture is an adjustable iris shutter placed between the lens and the camera. As the aperture is closed, depth perception of the viewed area increases. However, light is also blocked as the aperture is closed. Therefore, the greater the depth perception, the more illumination required.

Filters

Optical filters are used to clarify the image gathered by the lens. Two types of filters are used, a linearly polarizing filter and a band pass filter. The linearly polarizing filter reduces glare during sintering. This occurs because the glare from a liquid surface is normally polarized [Tipler, P. A., p. 867]. A second linearly polarizing filter is added when the intensity of the light incident on the sintered surface is very high. The second filter is rotated to reduce the amount of light that reaches the camera.

A band pass filter is used to eliminate thermal radiation when viewing metal sintering. When metals are sintered they have been observed to emit electromagnetic radiation in the red and yellow range and into the infrared spectrum. This radiation disrupts the quality of the video picture [Ogura, A. et. al., p. 753]. Therefore, the lighting system and band pass filter have been designed to observe the system in the 550 nm wavelength range with a wavelength band of 40 nm. This helps eliminate thermal radiation from metals.

In some video microscopy design specifications, the filters and lighting are designed to pass through any vapor phase which is present during the heating process. Voelkel and Mazumder designed a video microscopy system to view laser welding melt pools, and in doing so, the light source was designed to pass through any vaporized metal collecting around the melt pool. However, in the Selective Laser Sintering environment, the metal materials being viewed vary from copper and nickel to iron and steel as well as some ceramic materials. This material variability makes it difficult to tune the lighting and filter systems to the material specific optical properties. For this reason, designing the lighting and filtering systems to eliminate vapor interference was not undertaken. No adverse effects have been observed due to this neglect.

Lighting

The lighting system was also designed to combat the thermal radiation emitted by metals. Mercury vapor lamps were chosen as the illumination source because they emit 50% of their radiation at approximately 545 nm and 25% at 580 nm [Philips]. They are also capable of producing a large amount of light per bulb.

The light which is received by the photoreceptor chip in the camera is drastically reduced by the lens and filters [Reynolds, L. D., and J. F. Key p. 23]. Each of the polarizing filters reduces the incident light by 50%, as does the band pass filter for metals. The aperture also eliminates 50% or more of the incident light. This results in 6.25% of the 75% of useable light being received by the photoreceptor in the case of metals and 12.5% of the incident light being received in the case of polymers.

Multiple light sources were used to provide adequate illumination to the sintering area for viewing and to reduce or eliminate shadows. Three light sources were placed in increments of 120° to reduce the incidence of shadows in the system. If the lighting is not adequate or in the proper position, depth perception is hindered by shadows.

Experimental Results

Introduction

This section of the paper describes a selection of video microscopy experiments performed with the aforementioned system. A number of experiments were run on polycarbonate, wax and nylon powders. Stationary laser spots and single scan lines were studied under a variety of laser parameters.

Stationary laser spots were studied at low laser powers of the order of 1 Watt in order to slow down the sintering kinetics for observation. At higher powers, pyrolysis occurred immediately upon turning the laser on. Single scan lines studied were at conditions which allowed us to observe the sintering phenomena in great detail in relatively large time scales. The laser spot size used was approximately 3 mm. A few excerpts from our video presentation are shown below:

1. Figures 4-7 are frames taken from an experiment of a stationary laser spot on polycarbonate powder at a laser power of 1.5 Watts. Melting and collapse is followed by formation of a liquid pool. Bubbles of vapor are seen to form inside the liquid pool. This may be due to trapped air tying to escape. Charring in some regions suggests that pyrolysis is occuring.

Fig. 4

Fig. 5

Fig. 6

Fig. 7

2. Figures 8-11 are frames taken from an experiment of a stationary laser spot on wax powder at a laser power of 0.8 Watts. Melting is immediate with formation of strong convection currents. Some bubble formation is also observed.

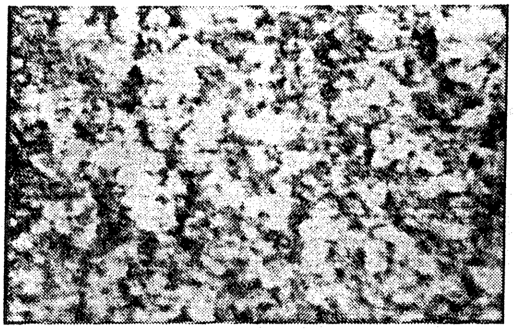

Fig. 8

Fig. 9

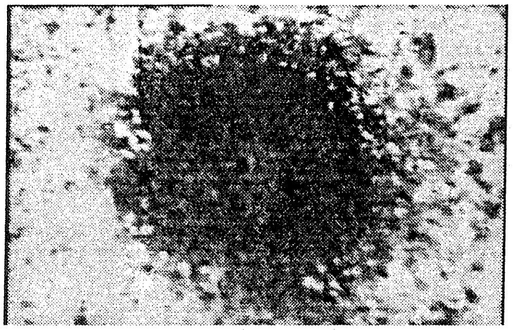

Fig. 10

Fig. 11

3. Figures 12-15 are frames taken from an experiment of a single line scan on nylon powder at a laser power of 1 Watt and a scan speed of 0.03 inches/s. Considerable amount of vapor bubbles are formed. Surface solification can be observed quite clearly at the end of line scan.

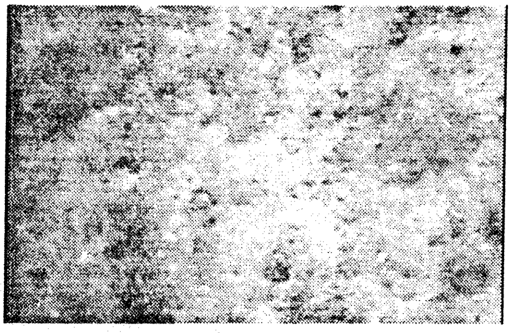

Fig. 12

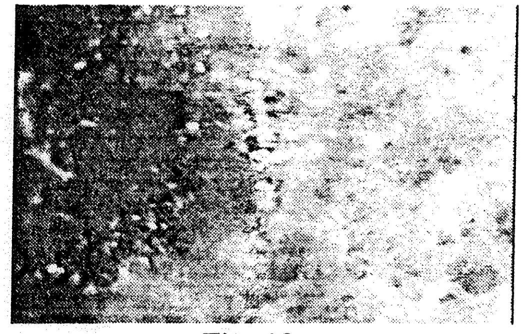

Fig. 13

Fig. 14

Fig. 15

Summary

The phenomenon of vapor bubble formation and entrapment in the liquid pool needs to be investigated further to determine the vapor content. At present, we believe it is due to air trying to escape; however, it might also be due to steam or gases evolved during pyrolysis. Reduction of vapor bubbles may help improve final part density.

While scanning lines at slow scan speeds, all three materials appeared to receive sufficient energy input to form a liquid layer that flowed and spread well. At higher scan speeds and higher laser fluence, unsintered powder seemed to wrap around the line being scanned. In the case of polycarbonate, this resulted in incomplete sintering of the material and significant depletion of surrounding material. In the case of nylon, there was considerable shrinkage and depletion of surrounding material.

Conclusions

A video microscopy system has been designed and implemented to observe selective laser sintering of polymers and metal materials. Initial experiments conducted with this system have allowed us to observe sintering and flow behavior in greater detail than ever before. This has allowed us to qualitatively evaluate the different sintering characteristics of the materials studied.

The next logical steps in these experiments would be:

1. Perform video microscopy experiments on the Selective Laser Sintering of metals.

2. Examine sintering behavior of spots and lines in these materials with a variety of boundary conditions describing the layer immediately underneath the sintering plane (e.g. conducting layer corresponding to a previously sintered layer).

3. Quantify sintering and densification rates based upon microscopic observation.

References

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